

Preliminary Results from the Alliance Icing Research Study (AIRS)

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Abstract

The Alliance Icing Research Study (AIRS) field project was conducted between 29 November 1999 and 19 February 2000. The main objectives of AIRS are 1) to improve our ability to remotely sense aircraft icing regions using satellite, aircraft or ground based systems; 2) to obtain additional data to characterize the icing environment which might be used in a revision of "Appendix C", the criteria used to certify aircraft for icing conditions; and 3) to improve our ability to forecast icing conditions and to understand how these conditions develop. An extensive array of remote sensing equipment was based at Mirabel airport to the north of Montreal. This instrumentation included five microwave radiometers, X-Band dual polarised scanning Doppler radar, X-Band vertically pointing Doppler radar, W-Band scanning Doppler radar, Ka-Band scanning Doppler radar, and a multiple field of view scanning polarised LIDAR. In addition, a scanning dual polarised S-band radar was operating at Ste. Anne de Bellevue, about 30 km SSE of Mirabel. The project aircraft were based out of Ottawa and flew most of their missions over the remote sensing equipment at Mirabel. The NRC Convair-580, the NASA Glenn Twin Otter, and a Learjet-25 operated by SPEC flew 25, 16 and 4 flights respectively. The Convair experienced 3 runback, 2-3 tail plane and 3-4 moderate-severe icing events. Icing was encountered on 4-5 flights with ambient temperatures colder than -20°C . One Convair severe icing event over Mirabel, associated with small droplets, occurred at -29°C . The Twin Otter saw moderate-severe icing on 2 days. In general, an excellent data set was obtained, that will provide good inter-comparisons between the aircraft in-situ measurements and the remote sensing data from Mirabel. The data will allow characterizations of the remote sensing instruments with respect to their abilities to detect and measure icing environments. Ultimately, this should allow for the design and development of advanced airport weather warning systems.

The AIRS Data Archive

**Peter Rodriguez
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Abstract

In support of the Alliance Icing Research Study (AIRS), the following web site has been established, <http://airs-icing.org>

The public access portion of the web site contains AIRS project documents and related publications. A password-protected section, available to AIRS participants, provides access to the AIRS Data Archive.

The Archive serves as a centralized vehicle for the project's data collection and distribution. This includes information collected by the Mirabel ground-based operations, the Ottawa ground-based operations, the research aircraft operations, and standard weather and satellite observing systems. The "toteboard", a matrix of all the datasets and their availability, will be presented to summarize the components of the AIRS archive.

The AIRS Data Protocol, whose thrust is open and timely access to all AIRS participants, governs all of the AIRS collected data. Requests for data are made to the AIRS data manager via an on-line form.

Overview of the AIRS In-situ Aircraft Data Archive

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Abstract

During AIRS, in-situ measurements were made using the NRC Convair-580 and NASA-Glenn Twin Otter research aircraft. The majority of the microphysics measurements have been analyzed, and the results have been made available to the AIRS research community through the AIRS web site. An overview of this data will be presented.

Specifically, the data set contains several different components including quality controlled 1-second 1D data, 30-second 1D and 2D data, 30-second analyzed in-cloud data and 10-second position data. The 1-second data includes analysis of parameters such as temperature, liquid water content, total water content, FSSP measurements, and Rosemount icing detector voltage. The 30-second averaged data include averages of the 1D variables, as well as the average 2D spectra. The 2D data are given in both digital and image formats. Both the 1-second and 30-second averaged analysis includes all in-flight periods from takeoff to landing.

The 30-second processed data include only in-cloud regions. For each 30-second in-cloud data point, the collective drop and ice crystal spectra were determined from one or more FSSP and 2D instruments. Parameters such as the droplet spectrum median volume diameter or the ice crystal spectrum reflectivity are then computed. Other parameters such as cloud phase and ice water content are also determined for each data point. The collective data analysis for the 30-second processed data are saved in a master spreadsheet file, which is suitable for processing bulk microphysics characteristics. The format of this analysis is identical to that of other projects such as CFDE I and III, which allows for combination of the data sets and detailed inter-comparisons.

It should be noted that this analysis does not include instruments such as the CPI, high frequency temperature probe, aircraft Ka-band radar, LIDAR, or DRI cloud scope.

Aircraft Icing in Glaciated and Mixed Phase Clouds

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Abstract

Ice accretion on aircraft is well known to result from supercooled cloud droplets freezing following impact on aircraft and instrument leading edges. The icing shape depends on conditions - static temperature (i.e. the droplet temperature), dynamic temperature, and aircraft and local airspeed. Deicing or anti-icing strategies, such as the use of boots and active heating, depend on knowledge of the ice build up characteristics and estimates of the thermal and mechanical rate processes. It has recently been realized that the presence of ice particles either intimately mixed with the supercooled phase (in a Poisson statistical sense) or in patches of differing spatial size distribution may influence the ice build up in ways as yet unknown. It is further known that problems may arise in jet engines by buildup of ingested ice. The accretion process may be examined in detail by a new aircraft mounted instrument, the DRI Cloudscope, which has been flown during recent projects. Particles impact on the Cloudscope window and are imaged by a video camera to the rear of the window, and a second high speed video camera which images the accreted particles from the side through a prism protruding into the airstream. Data collected in-flight during the recent Alliance Icing Research Study (AIRS) shows that ice particle striking the window heated just slightly warmer than 0°C melt immediately on contact. For an unheated window in a glaciated cloud, the ice particles appear to stick near the stagnation point and the thickness of this accreted ice increases to an equilibrium value, which may only be a few mm thick. An increase in thickness beyond this equilibrium value appears to be inhibited by the eroding effect of further ice particle impacts. It was evident that the deicing power requirements for a thermal anti-icing system should take into account total {ice + liquid} latent heat under some conditions, as both ice and liquid water were accreted and required melting and evaporation. Results will be compared with data obtained during Project CAMEX on the NASA DC-8 to demonstrate effects at lower static temperature (-50C) and higher impact velocities (200 m/s) than were available during AIRS.

Forecasting Icing for AIRS

Ben Bernstein and Marcia Politovich
NCAR

Abstract

NCAR has provided forecast support for inflight icing research for over 10 years --- for WISP, MWISP, SLDRP and AIRS 1. We find that forecasting for projects focuses our attention on those weather observables that really matter for icing. The results have been translated into our automated icing algorithms (IIDA and IIFA, the integrated icing diagnosis and forecast algorithms) which provide superior inflight icing forecasts for the CONUS.

We'll briefly review:

Tools: satellite imagery and derived products, radar mosaics, METARS, IIDA and IIFA --- what they tell us about where icing is and is not

Logistics: Time-of-day issues for some weather products (i.e. visible satellite imagery) and their impact on forecasting, communications

Results from '97 – '98 SLDRP: Forecasters guided the NASA Twin Otter into at least some SLD on 62% of the 46 flights, constituting 22% of total flight time. The NCAR satellite algorithm identified 73% of all icing occurrences, with most of the misses in warm-nose/low cloud top temperature situations. In-flight communications are important if not required for successful deployment of aircraft into icing regions.

New features: Changes to IIDA and IIFA, improved RUC microphysics, tests of intensity, type and threat fields

As in AIRS-1, NCAR would like to provide forecast support for AIRS-2.

Overview of the Experimental Canadian Forecast System during AIRS

Anna Glazer
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Abstract

To provide special forecasts required during AIRS, the Canadian Meteorological Centre in collaboration with scientists of the Cloud Physics Research Division (Meteorological Service of Canada) designed a prototype version of the Global Multiscale Model (GEM-AIRS). This version of GEM was initialized daily at 0 UTC and was integrated for 48 hours. The GEM-AIRS configuration included a mixed-phase cloud scheme and various cloud microphysical variables were calculated to support flight operations during the AIRS project. The forecast system configuration will be described and examples of typical forecast products will be presented.

Ground based microwave Liquid Water Path measurements at Mirabel and Ottawa

**Walter Strapp and Zlatko Vukovic
Meteorological Service of Canada**

Abstract

Cloud Liquid Water Path (LWP) estimates from passive microwave radiometers at Mirabel and Ottawa during AIRS have been examined. One of the major limitations of these data is contamination during rain events by wetting of the instrument and by scattering effects, which will be major technical problem for any future nowcasting system for icing avoidance. Statistics on the percentage of time during AIRS with unusable data due to this effect are presented. Cumulative frequency distributions of LWP for Mirabel and

Ottawa for periods without rain are presented. A brief review of other work related to comparison of physical and statistical retrievals for LWP estimation, and comparison of Attex and Radiometrics LWP estimates will also be described.

Multi-frequency Radar Estimation of Cloud Water Content

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Abstract

The University of Massachusetts Cloud Profiling Radar System (CPRS) is a truck-based dual-frequency (94.92 GHz and 33.12 GHz), polarimetric Doppler radar. It has a programmable pedestal facilitating various scanning modes and a high-speed VXI-bus-based data acquisition and digital signal processing (DSP) system. During the AIRS project, CPRS was deployed at Mirabel airport, Montreal, Quebec, Canada, in coordination with other sensors including the McMaster University X-band radar, NASA Twin Otter and AES Convair research aircraft.

Hydrometeor characteristics, such as cloud water content and mean particle diameter, can be derived from differences in backscattered power or Doppler spectra at different radar frequencies. These differences are due to Mie scattering and differential extinction. In order to combine data from multi-frequency radars, a neural network algorithm was used to retrieve ice and liquid cloud particle properties from the measurements collected by the CPRS and McMaster X-band radar during AIRS. The results were compared with those retrieved from aircraft in-situ measurements.

Summary of Results from SPEC Participation in AIRS

Paul Lawson
SPEC Inc.

Abstract

SPEC Incorporated operated a remote sensing package consisting of a dual-wavelength (X and K_a-Band) radar system and a dual-frequency (22 and 37 GHz) microwave radiometer. The SPEC Learjet research aircraft was equipped for making microphysical measurements and was used to make in-situ comparisons with the radar and radiometers observations.

The Learjet executed a unique flight pattern whereby it made an instrument approach to the Mirabel airport and then executed a steep (12° angle and 5000 fpm) climb up the radar/radiometer beam. A custom onboard navigation system enabled the Lear crew to accurately climb within the radar/radiometer beam. Due to limited weather opportunities, only six Learjet ascents were made up the radar beams.

In addition to data collected by the Learjet, the NRC Convair executed spiral descents and stepped-ascent level flight legs in the vicinity of the Mirabel airport. A portion of this data set was also used to evaluate the performance of the combined sensor package. Also, data from the UMASS and (to a much lesser extent) the McMaster radar were incorporated into this analysis.

The principal results of this research can be summarized as follows:

1. Mixed-phase icing conditions were the rule rather than the exception, and the mixed-phase clouds often contained ice particles $> \sim 1.5$ mm in size, which produce Non-Rayleigh scattering of K_a-Band radar signals.
2. Regions in mixed-phased condition with very low ($< \sim 0.05$ gm⁻³) SLWC are difficult to quantify, due to the “false LWC signal” from ice on the hot-wire probes. Also, in some cases, the Rosemount icing detector did not register SLWC in regions where the CPI appeared to see low concentrations of water drops. This may be because the SLWC was below the theoretical detection limit of the icing detector.
3. Results from the Learjet slant ascents showed that the microwave radiometer registered about a factor of two higher than the integrated liquid water path using the hot-wire probes.
4. Based on the limited data collected, combined radiometric and radar measurements produced a moderately reliable method to eliminate “false positives”, and, using the UMASS Neural Net algorithm, identify regions with SLWC $> \sim 0.1$ gm⁻³ that extended for at least 2 km.

Polarization Diversity Radar Measurements in Support of Aircraft Icing Studies

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**I. Zawadzki
McGill University**

**B. Currie
McMaster University**

Abstract

There were two ground-based radars with polarization diversity used during the AIRS field project: They were: (1) the McGill University S-band scanning Doppler radar using the slant-45 polarization scheme and located about 20 km west of Montreal, and (2) the McMaster University scanning portable X-band Doppler radar using an alternate H-V polarization scheme and located at Mirabel airport about 30 km NNW of the S-band radar. The S-band radar carried out 24-angle volume scans every 5 min throughout the project. The X-band radar focused data collection (a series of stares, RHIs and sector volume scans) on the region in the vicinity of the cloud physics research aircraft that were operating near Mirabel. Results from the December 10 AIRS case, an example of severe icing, will focus on techniques that are being used to compare the observations between the two radars and between the radars and the two cloud physics aircraft.

Doppler radar signatures of in-flight icing conditions

**Frederic Fabry, Isztar Zawadzki, Candace Bell, and Chantal Cote
McGill University**

Abstract

Detection of supercooled cloud and drizzle is particularly difficult, especially in the presence of ice crystals of much stronger reflectivity. Although direct detection is difficult, the occurrence of icing conditions can often be determined by Doppler radars as supercooled water leaves clues of its presence via its interaction with the snow crystals. When snowflakes fall through a supercooled cloud, they first grow quickly, resulting in a large dZ/dh , and then get rimed, resulting in denser crystals that fall faster. When rimed crystals melt, the resulting bright band will be considerably weaker. Some of these conditions can be detected by conventional scanning radars, while others require observations by a vertically pointing radar. Comparisons of prediction of icing conditions with radiometers and aircraft data show that these techniques have considerable potential. Finally, supercooled drizzle in the presence of snow can be detected by vertically pointing radars as it forms a distinct Doppler mode considerably slower than that of the rimed snow.

GRIDS: Ground-based Remote Icing Detection System

Madison J. Post
NOAA

Abstract

NOAA/ETL, under FAA sponsorship and possibly in conjunction with other partners, is developing an operational system to unambiguously detect Large Super-cooled Droplets (SLDs) via remote sensing in the vicinity of at-risk air traffic centers. The system is based on 35-GHz polarimetric radar observations at an elevation angle of 40E, a two-channel microwave radiometer, and hourly ingest of local temperature profiles (radiosondes or model analyses). The observational techniques for this system have been validated experimentally during recent MWISP campaigns. They are unaffected by absolute calibration or the effects of attenuation. The target system, fully autonomous and highly sensitive, will be preceded by a semi-autonomous, less-sensitive “upgradable” system that may be ready in time for AIRS-II.

Polarization of thermal microwave radiation by clouds during AIRS

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J.W. Strapp, and G.A. Isaac
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Abstract

It was found that the thermal microwave radiation of cloud atmosphere may be polarized. The measurements of the microwave radiation were conducted during AIRS project by dual-polarized 37GHz and 85GHz radiometers incline at 25° to the horizon. Polarization of the microwave radiation at frequencies 37GHz and 85GHz was observed during approximately 30% of time clouds were observed. The characteristic time of observation of polarization may vary from few minutes to few hours. The polarization contrast $\Delta T = T_h - T_v$ was found to be both positive and negative and it does not correlate with LWP. Theoretical calculations show that the observed polarization may be related to the presence of ice particles.

Progress on the A-Band Cloud Parameters

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Abstract

The AIRS campaign provided an opportunity to collect nadir spectra from 3 small spectrographs and an FTS in the manner similar to the proposed PABSI instrument for the CloudSat satellite.

Using the spectra collected during AIRS, an algorithm is in development to process the A-band spectra in to the more useful measurement of photon path lengths (PPL). Using Turbo C, code has been written which takes the raw spectra from the Fourier Transform Spectrometer (FTS), applies a base line correction, computes the PPL for 15 wavenumber intervals (corresponding to the absorption bands), and computes the error in the PPL. The equation for the PPL calculations is derived from the approximation of Beer's Law: τ is the transmission, l the PPL, and a is a constant which disappears when the ratio,

$$\tau = e^{-al}$$

between the radiances for cloudy and clear skies is taken.

The program also has the ability to process spectra with a resolution of 1, 4, and 25 wavenumbers. A resolution of 4 wavenumbers is preferable to that of 1 not only because it removes the doublet within each absorption band, but it also reduces the noise that distorts the spectra. The derived PPLs are more consistent and less noisy than the preliminary 1 wavenumber analysis. More work is underway to determine if it is possible to use 25 wavenumber resolution to the PPL, as this would reduce the memory required to store the spectra, as well as the time to complete the computations.

Comparisons of lidar retrievals with aircraft *in situ* measurements of cloud liquid water content and effective droplet diameter

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DREV

Abstract

Our group participated in the Mirabel AIRS program with a scanning, dual polarization, multiple-field-of-view (MFOV) lidar. The polarization channels are used to differentiate between liquid and solid/mixed phase clouds. RHI scans of backscatter and depolarization will be presented that illustrate very well the structure and phase of the clouds under investigation. The MFOV technique allows retrieval, with range resolution, of the cloud extinction coefficient and effective droplet diameter by exploiting the information contained in the multiple scattering contributions. From these parameters, the liquid water content (LWC) of liquid phase clouds can easily be calculated. In this paper, we compare our LWC and droplet size retrievals with the Convair 580 *in situ* measurements for the periods when the aircraft was flying in the Mirabel area. The results show good correlation between the lidar solutions and the *in situ* data but a constant bias. On average, the lidar-derived LWC is 20-25% less than the aircraft measurements and the effective diameter, 20-25% greater. These differences are reduced to about 10% if we confine the aircraft data to the cloud base region and screen out one event on account of incompatibility between the hotwire measurements and the recorded lidar penetration depth. Despite the differences, these comparison results constitute a good validation of the MFOV retrieval principle. One additional observation is that the lidar solutions are, within 20-25%, statistically representative of the complete layer in spite of the limited penetration depth. It would seem, therefore, that the utility of the lidar is greater than anticipated. Long-term MFOV lidar monitoring could thus become a viable and economical option for cloud studies. The addition of a microwave radiometer could provide the needed estimate of the full layer thickness by combining average LWC and integrated water column.

Multi-sensor spaceborne observations of winter cloud systems during AIRS campaigns.

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CRESTech / York University**

Abstract

Optical and microwave sensors on polar orbiting satellites provided frequent coverage of AIRS study areas. Special Scanning Microwave Imager (SSM/I) data for December 2, 1999 to February 17, 2000 were acquired and processed. Advanced very High Resolution Radiometer data for the same period and, when it was possible, as close in time to SSM/I overpass was also acquired. Our main objective was to test the input of cloud top temperatures into SSM/I cloud parameters retrieval algorithms. The synergy between two types of sensors was explored using radiative transfer model. The use of models has also allowed derivation of methodology for uncoupling surface and atmospheric contributions to signals measured by a spaceborne sensor.

Our second objective was to derive information about spatial variability of cloud optical depths, cloud albedo, and other parameters. The differences in spatial resolution between SSM/I and AVHRR as well as availability of AVHRR images at 1 km and 4-km resolution were used in this analysis. Preliminary results of the methodology used will be discussed in this presentation by presenting analysis of several case studies.

Use of Aircraft and Remote Sensing Observations to Study Cloud Microphysical Parameters During AIRS: A Case Study of the Mixed Phased Clouds

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Abstract

Observations collected during the Alliance Icing Research Study (AIRS) field project that took place over the Ontario and Quebec region of Canada during winter of 1999 and 2000 are used in this paper. The purpose of this work is to better understand relationships between microphysical and dynamical processes, and compare the observations retrieved from the aircraft and remote sensing platforms e.g. NOAA AVHRR, UMass W-Ka band Doppler radar, microwave radiometer, airborne Ka band cloud radar, and McGill X-band vertical pointing Doppler radar. Three cases from AIRS were used in the present work. These cases were chosen based on cloud particle phase and large-scale cloud dynamics. For the first case, clouds formed related to a cold outbreak on Feb. 5 2000 and only ice crystals within the cloud were observed. For the second case, a large cloud system formed related to a strong 500 mb short wave and a low over the Great Lakes region on Dec.15/16, 1999. Clouds on this day had mixed phase conditions, with a large amount of liquid water content. For the third case, clouds were related to a weak upper-level short wave on Jan. 28, 2000, with a low amount of LWC. For case 1, the ice crystal number concentration (N_i), as a raw shadow information, was about 500 l^{-1} at about -35°C and no LWC was observed. For the mixed-phase conditions in case 2, droplet number concentration (N_d) $\sim 200 \text{ cm}^{-3}$, ice water content (IWC) $\sim 0.05 \text{ g m}^{-3}$, liquid water content (LWC) $\sim 0.35 \text{ g m}^{-3}$, and $N_i \sim 400 \text{ l}^{-1}$ were observed at -10°C from the aircraft over the Mirabel remote sensing site. For case 3, although N_d reached 200 cm^{-3} , LWC was only about 0.1 g m^{-3} at -20°C and N_i was less than 50 l^{-1} . Preliminary results indicate that significant differences are found in the microphysical parameters obtained from different platforms. It is concluded that variability of microphysical parameters in the vertical and horizontal, together with cloud development in time and space, and instrument characteristics should be considered in studies of mixed-phase and ice clouds.